The Primacy of Drawing in Design

by

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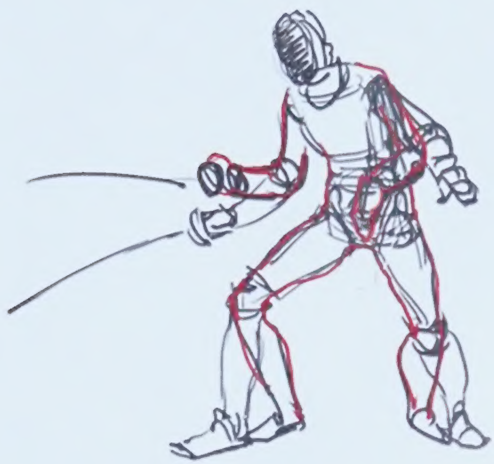

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Fig. 1. Leonardo da Vinci, *Rearing Horse*. 1483-1498. Red chalk, 15.3x14.2 cm. Winsor Castle, the Royal Library. From: the Art Archive, http://www.artchive.com/artchive/L/leonardo/leonardo_rearing_horse.jpg.html (accessed September 23)

“

I'm always amazed when I see somebody that can draw a horse. I can't figure out how they can possibly do it. You know, they can actually reproduce a horse with pencil and paper... it's terrific. Now, I can't draw a horse or anything else but I can write jokes. It's hard not to write them. If I walk down the street it's like my normal conversation, you know, it just comes out that way, you know what I mean?[1]

”

- Woody Allen

[1] Woody Allen, quoted in *Woody Allen: A Documentary*, directed by Robert B. Weide (2012. North Hollywood, CA: Whyaduck Productions, 2012) DVD.

AKNOWLEDGEMENTS

First, I would like to thank my advisor Tim Antoniuk for his advice and guidance over the years. This project would not have been possible where it not for his unwavering support.

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I have also been fortunate to be challenged and encouraged by Guido Tondino. Guido's thoughts and recommendation informed major edits to this paper.

Finally, I would like to thank my family, my parents and my brother, for all their support throughout the years.

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ABSTRACT

The goal of this thesis and the accompanying show is to explore the relationship between drawing, authentic designerly activity and 3d modelling. I argue that drawing is central to design practice, that it enables designerly activity, and that design drawing should be used as a model for subsequent explorations of form in 3 dimensions. I make the case for drawing not as an activity that complements design practice but instead as itself representing a form of design inquiry, or design thinking. In order to make this point I trace back the history of design and drawing while looking to my own practice as a designer as well as the analyses of drawing done by Schön and Gedenryd who talk about drawing in the contexts of action research and cognitive science respectively. The practical project that accompanies this paper begins with a thorough exploration in drawing and then moves on to other elaborative design activities whose purpose is to advance the design process while retaining as much as possible not only the vision of the early drawing phase, but also its nature as inquiry.

LIST OF IMAGES

PART 1: ORIGINS

In the Italian language the word "designo" can be used to refer not only to a drawing of a design, but also to the design itself as well as the process of design ("disegnare"). This peculiarity of language is revealing of the close relationship between drawing and design dating back to the common inception of both practices some 500 years ago. Although activities we can identify as drawing or design date much further back, it is during this period, that is, the Renaissance, that we see the beginning of the separation of design from making, which ultimately led to the relationship between engineers, inventors, industrial designers, architects and those trades and manufacturers who carry out their visions. Importantly, this process of separation is also closely related to the development of artists and designers' conception of their thought processes as well as drawing conventions.

The Emergence of Design and Drawing

Drawing and its related practices (ie any time we put pencil to paper such as for writing or performing mathematical calculations) are so natural to us in their modern forms that we rarely think of the technology and historical developments that have made them possible. These implements feel to us like a natural extension of our bodies and the things we produce with them (language, drawing, mathematical equations, musical notation, etc.) feel like natural extensions of our thoughts. However, the implements involved in making marks on paper are surprisingly sophisticated when we look at them closely. The modern pencil, for example, is a relatively recent invention dating back to the 19th century. Prior to this period, artists and designers used sticks of graphite or other materials to make marks on paper. This is true of all aspects of these implements from the manufacture of paper to the properties of the various tools (quills vs pens, graphite sticks vs pencils, etc). It is impossible to state with significant certainty the origins of drawing in human societies. Practices we can describe as drawing can be found long before the beginning of recorded history in places like the caves at Lascaux. However, the modern activity of drawing and its relationship to those professions which, at their most basic level, rely on the manipulation of visual information

(especially art, design and architecture), originates at a relatively specific point in history, that is, roughly 500 years ago.

It is during this time, that is the late medieval period, that paper arrived in the West by way of Islam from China. By the time of the Renaissance its widespread availability and relative cheapness led artists, designers and any manner of professionals who produced man made artefacts to use it as a medium for quickly jotting down ideas, developing them and eventually storing them in sketchbooks for future reference. An important characteristic of paper was its relative perishability compared to expensive and hard to come by materials such as velum, which had previously been used to produce manuscripts, scrolls, and other forms of drawing and illustration. One could pour any number of visual ideas on paper and not feel any pressure of wasting materials in doing so. This led to the development of sketching and drawing methods that were loose, portable and which could be easily stored. Artists could now make extensive studies from nature while engineers and designers could explore ideas much more freely. These advances occurred in conjunction with the development of linear perspective which, when used intuitively by skilled draughtsmen, had an important influence on the development of design practice.

Fig. 2. Example of mechanical design drawing prior to the adoption of perspective drawing. Note the flat but descriptive mode of representation. Guido da Vigevano, *Armoured assault wagon*. Early 14th c. Bibliothèque Nationale de France, Paris. From: http://en.wikipedia.org/wiki/File:Skizze_Kurbelwagen_%28Vigevano%29.jpeg

Prior to the Renaissance, drawings of architecture or mechanical devices (or anything for that matter) in the West did not depict their subjects from one view with consistent indications of the directions of different planes in space; top, side, front, etc., as is

common with most drawings today. Instead, during the medieval period and before, it was common to depict subjects either from multiple singular side views, such as elevations and plans used by architects, or from a variety of points of view at the same time, as was common with engineering drawings of mechanical devices. While architectural drawings would appear familiar to us today (plans, elevations, etc.) drawings made by engineers often appear crude to our modern eyes, as if the draughtsman is unskilled. However, these types of "flat" drawings were made with great skill and ingenuity to ensure the object was described more fully than from any single view. They served a purpose and they did so well. Importantly, a shift occurred during the Renaissance which marked the beginning of drawing from one view, and eventually the development of linear perspective which ensured, for those who studied it, that these new views would appear "correctly" to the viewer as they would to the human eye in life. This new type of drawing was much easier to interpret by the viewer and became of central importance for architects and engineers who could now quickly "read" their own drawings.

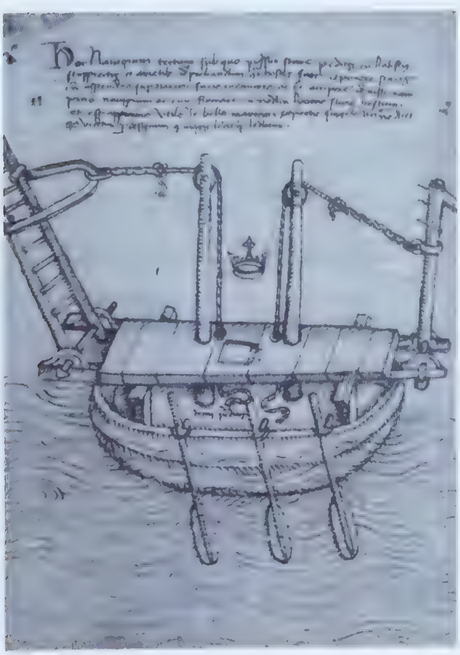

Fig. 3. Military naval boat grappler from Taccola's *De Machinis* manuscript. (Detail from Munich, Bayerische Staatsbibliothek, Codex Latinus Monacensis 28800, fol. 81^{v}; reproduced in McGee, 2004)

Fig. 4. Variation of military naval boat grappler from Taccola's *De Machinis* manuscript. (Detail from Munich, Bayerische Staatsbibliothek, Codex Latinus Monacensis 28800, fol. 90^{v}; reproduced in McGee, 2004)

However, while Leonardo's sketches are undoubtedly more famous and arguably present a more developed sample of the new type of drawing, it is in fact in the manuscripts of Mariano di Jacobi detto Taccola, a civic works engineer from the town of Siena, who, during the mid-1400s, wrote a number of manuscripts which dealt with civil and military technology, that we can "follow a person actually working out technical ideas for the first time in history"[2]. In 1433 Taccola submitted to his patron the last two books in a series of four known as "De Ingeneis". Books one and two were never completed and their empty pages were later used as notebooks to develop rough sketches for another manuscript called "de Machinis". These sketches for "de Machinis" show Taccola applying principles of perspective instead of making flat drawings in the medieval tradition. "Taccola is able to show us three sides of his ships at once so that they have volume and take up space. He adds to this sense of three-dimensional mass and volume through the use of shadowing"[3]. Furthermore, these sketches appear to show Taccola "thinking" through sketching:

> Taccola's technique does more than allow the rapid generation of alternatives. It allows a systematic holding of some elements steady while others are explored in successive iterations of the design. More than exploration, Taccola's style provides him with a method of systematic investigation through variation.[4]

Interestingly, Taccola is engaged in a type of exploration that today would be typical of industrial design. He is investigating usability by moving various pieces of his design around and trying to imagine the use scenarios that arise from such changes and their practical effects on people.

> It appears that Taccola's drawing technique allows him to pass beyond the context of construction to investigate the future context of use. Thus, there is nothing impossible about placing the grappler on the side of a boat, as Taccola does in his initial sketches. The pulley arrangement would work. But it is not very likely to be effective in battle, particularly if the enemy ship approaches from the side. Seemingly aware of this, in his next sketch Taccola considers dropping the grappler from the bow, which would be more effective, although the stern would be unprotected. Hence, the double-grappler of his next

[2] David McGee, "The Origins of Early Modern Machine Design." In *Picturing Machines 1400-1700*, edited by Wolfgang Fefevre (Cambridge, Massachusetts: The MIT Press, 2004), 73.
[3] McGee, "The Origins of Early Modern Machine Design," 73.
[4] McGee, "The Origins of Early Modern Machine Design," 76.

> drawing. Similarly, there is nothing physically better about dropping grappling hooks from overhead beams, as opposed to pulleys, or double pulleys. Again, the cause of variation appears to be Taccola's awareness of awkwardness or ineffectiveness for the humans who actually have to use them.[5]

The new drawing, and the manner in which it can be interpreted quickly and iterated upon, makes possible a freeform exploration which is removed from the restrictions of materials and physics. While this may seem like a limitation, it is, in fact, the very thing that attracted so many to it. It allowed, and for many designers today continues to allow, the focus to be placed on the vision behind the end product, which often includes aspects of the logistics of building, but, importantly, is removed from the difficulties of making or prototyping.

> In the absence of materials, dimensions, and physics, Taccola is able to iterate freely, in both senses of the word. There is no cost of construction and no cost of failure. He is not constrained as the expert maker would be.[6]

These new developments in the practice of drawing make possible the separation of the planning of a product from its making, a distinction which Heskett[7] identifies as the beginning of modern design practice. Before the Renaissance, manufacturers and designers in the modern sense were practically non-existent. A small group of people, usually craftsmen under the supervision of a master, were responsible for designing and building products from start to finish. Crucially, there was relatively little specialization and, importantly, no separation between the conception of a product and its design. The two were regarded as fundamentally connected, that is, if the distinction between the two was ever made. The notion of a person building what another person has specified, especially when the person specifying is also not a craftsman with years of practical experience, would have been a strange notion at that time.

However, as trade expanded, workshops began to serve larger markets and increasingly wealthier churches and princely courts. Slowly, over a period of centuries, demand increased and so did the stress on the individual craftsman. It became increasingly common for artisans in a shop to specialize in order to handle the larger volume of work.

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[5] McGee, "The Origins of Early Modern Machine Design," 78.
[6] McGee, "The Origins of Early Modern Machine Design," 78
[7] John Heskett, *Industrial Design* (London: Thames and Hudson, 1980), 10

For example, in an armory it would have become increasingly common for the master to spend more time with clients and dealing with budgets and management while the junior craftsmen would build under the supervision of the master according to his indication. In short, division of labor and, over time, specialized trades started to appear.

From Craft to Design

> Around the sixteenth century, there emerged in most of the European languages the term "design" or its equivalent. The emergence of the word coincided with the need to describe the occupation of designing. That is not to suggest that designing was a new activity, rather that it was being separated out from wider productive activity and recognized as a function in its own right. This recognition can be said to constitute a separation of hand and brain, of manual and intellectual work; and the separation of the conceptual part of work from the labour process. Above all, the term indicated that *designing* was to be separated from *doing.* [8]

This historical trajectory is particularly evident in architecture, where due to the size and complexity of construction, specialization occurred earlier than in other areas. As with other crafts that were later separated into design and manufacturing, architects of the medieval period were not really architects in the modern sense, but tradesmen, namely masons. The master mason was present on site at all times overseeing and working alongside his crew. In fact, as late as the Renaissance, some architects, such as Andrea Palladio, were still trained as masons and later "promoted" to the role of architect. However, importantly, by the time of the Renaissance, the separation of masons and architects became much more pronounced. Many architects of the Renaissance, especially those working on the larger princely or church commissions, were no longer part of construction crews and spent relatively little of their time on site. Instead, they specified through drawings what was to be built.

Due to this early separation, it is relatively easy, even when going as far back as the Renaissance, to identify architects working in a manner that is instantly recognizable today as architecture. In other design domains such identification is harder to do. Take for example furniture design which continued to be the domain of craftsmen as late as

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[8] Mike Cooley, "From Brunelleschi to CAD-CAM," in *Design after Modernism: Beyond the Object* edited by John Thackara. (New York: Thames and Hudson, 1988), 197.

the 19th century. For this reason architecture is often regarded as the parent discipline of design professions, most of which took on their modern forms during the 18th - 19th centuries when the industrial revolution imposed division of labour on craftsmen of every kind. This is, of course, a contentious proposition given that some design fields, can be argued, developed independently. Graphic/communication/information design has strong roots in printing shops, calligraphy, and typography, while modern product design began when artists were hired by manufacturers in the 19th century to make their products visually appealing after the fact. To this day industrial designers struggle with people's perception of them as mere stylists. However, in one key respect architecture has a strong claim of pre-eminence - in being the first design related profession to separate plan from making, it was also the first to adapt drawing methods like Taccola's or later Leonardo's for this purpose. In other words, the drawing conventions used in every modern design discipline, namely the practice often referred to as design-by-drawing was first adapted and used in a substantial way by architects during the Renaissance.

Creativity in Practice versus the Divine

These early architects, in conjunction with artists and other creative intellectuals of the time were also deeply involved in the humanist project of the Renaissance. These new thinkers stressed their own individuality as human beings as opposed to being defined by the relationship of man with God which dominated medieval discourse. "Renaissance men" like Alberti, Raphael, and Michelangelo stressed the nature of their own personal creativity as stemming from their own practice and thinking processes as opposed to divine inspiration or other sources. This may seem as a common sense position today, but, by the standards of the time, it was a radical break with the past. In the preceding historical periods, creativity, in the modern sense of the word, did not exist. The ancient Greeks had no words for it and regarded the vast majority of what today we would refer to as creative people (architects, sculptors, musicians, etc.) as makers of things that imitate nature as opposed to inventors of new and original works. Only Greek poets were understood to possess some creativity. The characters, situations, and words they invented, while maybe inspired by reality, were regarded as new and original creations when put together by the poet into a play or epic poem. This exception lasted for

thousands of years. In the Judeo-Christian tradition, the understanding of creation was closely tied to the Bible and The Book of Genesis. God was regarded as the only one who can create or imagine something from nothing and all human imagination was simply people discovering what already is, which by default was originally created by god. It was not until the Renaissance that imagination began to be seen as springing from the individual and not from divine revelation. Artists and architects made sure to stress the importance of their own individuality and the uniqueness of their personal perspective, sometimes dangerously so bordering on what some regarded as blasphemy. How could a mere man claim to be creative as God was?

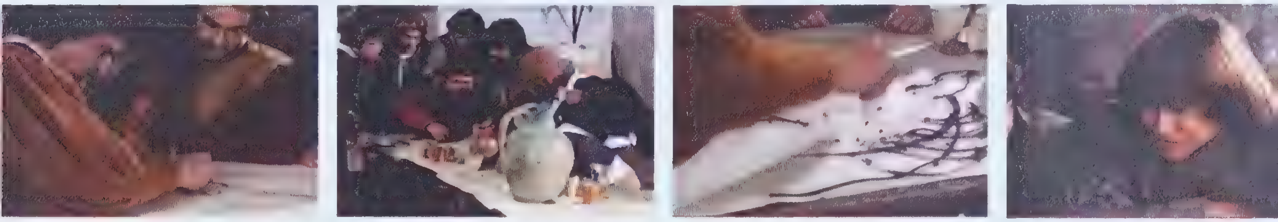

Fig. 5. Verrochio makes an impromtu dinnertable sketch of his plans for the famous equestrain statue of the mercenary Bartolomeo Colleoni. Hi apprentices flock to watch him draw. (stills from *The Life of Leonardo da Vinci, Part I,* 50:20 dir by Renato Castelliani, 1971. Retrieved from Ques Video's youtube channel)

It is in these "Renaissance Men" of the 1400s and 1500s with rather high opinions of themselves (not unlike their modern equivalents), who despite not being referred to as designers today, that we can first identify something like modern design practices as well as figures whom we may refer to as prototypical designers. Men such as Verrochio, Leonardo and countless others, who ran vast workshops and specified to their apprentices what to build and how by providing drawings and sketches of their intentions. They often designed practical objects such as furniture, clothing, etc. and even those works regarded as art in our time served practical purposes in theirs. The patronizing of grandiose Renaissance projects was as much a self-aggrandizing gesture of intimidation as a modern day Wall Street investor who drives a Ferrari or wears an Armani suit. These renaissance designers dealt with fickle clients, ran studios whose products ranged from cutlery to architecture, and competed against one another for projects. Despite their being usually recognized as artists, in their own time they were not judged by critics, curators, and collectors but instead by clients, peers, and users and were forced to content with the day to day realities of budgets, project management, and many other issues all too familiar to designers today. Critically, the practice of these

masters, as well as their own conception of their creativity and thought processes, became intimately tied to their drawings through which they specified to their workers their visions and how to carry them out.

PART 2: PRACTICE AND COGNITION

Drawing in Current Design Practice

In a recent *New York Times* opinion piece[9], the architect Michael Graves lamented the ever decreasing importance architects and designers accord to the practice of drawing. On the one hand, the role of drawing appears to be universally acknowledged as central, while on the other its actual practice is becoming ever more rare. Meanwhile, various computer tools, and particularly in recent years parametric software, have become ever more popular. Their widespread use is evident in recently highly publicised projects and in the offices of major architects and designers of every kind.

> With its tremendous ability to organize and present data, the computer is transforming every aspect of how architects work, from sketching their first impressions of an idea to creating complex construction documents for contractors. For centuries, the noun "digit" (from the Latin "digitus") has been defined as "finger," but now its adjectival form, "digital," relates to data. Are our hands becoming obsolete as creative tools? Are they being replaced by machines? [10]

Graves does not dismiss the use of computers altogether. Computer tools have undoubtedly brought manufacturing and construction closer than ever before to the specifications of designers. Moreover, the computer makes possible new and complex geometries that were practically impossible to describe previously. Graves himself admits the results are often interesting. However, he also brings up a crucial point which no staunch proponent of CAD software to date has really been able to address:

> Drawings are not just end products: they are part of the thought process of architectural design. Drawings express the interaction of our minds, eyes and hands. [11]

What is this interaction of "our minds, eyes and hands" Graves talks about? And, importantly, why does so called parametric CAD software or more generally

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[9] Michael Graves, "Architecture and the Lost Art of Drawing", New York Times, September 1, 2012, accessed August 20, 2014, http://www.nytimes.com/2012/09/02/opinion/sunday/architecture-and-the-lost-art-of-drawing.html?pagewanted=all&_r=0
[10] Graves, "Architecture and the Lost Art of Drawing."
[11] Graves, "Architecture and the Lost Art of Drawing."

conventional CAD software fail to address this interaction? One way to delve deeper into this question is by considering the effect that using a program like Rhino, Revit, or Solidworks has on the working practices of designers relative to engaging in drawing activity or other traditional activities like model making or clay sculpting. Importantly, I argue the effect of using the computer is remarkably similar to that of adopting one of the design methods prescribed by early design researchers.

Design as Methods and Algorithms

The design methods movement emerged out of the attempts of early design researchers to explain the working processes of designers and to describe them in such a way that they could be repeated by others simply by following through a similar set of steps. In order to achieve this, they tried to break down the activity of designing into more or less repeatable prescriptive steps. This breaking down into steps resulted in a multitude of so called design methods.

> A design method is a normative scheme that specifies in detail a certain working procedure, the activities to perform, and also a specific order in which the activities should be carried out. It is usually very precise, and the designer is to follow it meticulously.[12]

Typically design methods are described through charts and diagrams "that resemble, to varying degrees, the diagrams and calculations that computer programmers use." These diagrams are often filled with a multitude of arrows pointing in one direction or another, which, when followed step by step, indicate the course of progress or the evolution of the design from start to finish.

The most lasting idea of design methods, and which to this day is often taught in some design schools, is the three part breakdown of the design process into the following linear sequence: analysis, synthesis, evaluation. Jones Chris Jones, an early proponent of design methods, wrote the following in his book "Design Methods", which constitutes one of the core early publications in the field:

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[12] Henrik Gedenryd, "How designers work: making sense of authentic cognitive activities" (PhD diss., Lund University, 1998), 19.

One of the simplest and most common observations about designing, and one upon which many writers agree, is that it includes the three essential stages of analysis, synthesis and evaluation. These can be described in simple words as "breaking the problem into pieces", "putting the pieces together in a new way" and "testing to discover the consequences of putting the new arrangement into practice" [13]

In its most common manifestation this breakdown looks somewhat like this:

ANALYSIS		SYNTHESIS		EVALUATION
ACTION: RESEARCH THE PROBLEM OUTCOME: PROBLEM STATEMENT	→	ACTION: WORK ON SOLUTION OUTCOME: SOLUTION	→	ACTION: EVALUATE SOLUTION

Fig. 6. The triad of analysis, synthesis evaluation. Figure by the author.

The problem with this triad, and hence virtually all design methods, is that it doesn't actually describe the activity of designing. At best, design methods can be used for project management or to structure already known design projects and how to carry them out. Take for instance the auto industry, which over a period of decades has refined its working method to the point that they can effectively break it down minutely into a linear sequence of activities: sketching, 1:1 scale clay models, using designer's tape, etc. Many designers yearn for this kind of certainty in regards to their own working processes especially when having to explain to clients, manufacturers and engineers how a particular project is to evolve over time and what will be done, when, and how. However, for many of the critical problems that designers face on a day to day basis, design methods provide little insight into the nature of designerly practices. When confronted with the types of problems designers claim to be good at solving (or at least coming up with workable solutions for) like wicked problems or problems that involve significant unknowns and untreaded ground, design methods are almost entirely useless.

The Failure of Method

The failure of design methods is well known and documented, which makes their enduring appeal somewhat baffling. Only a few years after the publication of core early works in the field the very authors of those works denounced the movement as a whole.

[13] Jones Chris Jones, *Design Methods* (New York: Van Nostrand Reinhold, 1992), 63.

One notable example was the architect Christopher Alexander whose *Notes on the Synthesis of Form* continues to be read today as an early influential work in design studies. He had this to say only a few years after the publication of that book:

> ...there is so little in what is called "design methods" that has anything useful to say about how to design buildings that I never even read the literature any more. ...I would say forget it, forget the whole thing. Period. Until those people who talk about design methods are actually engaged in the problem of creating buildings and actually trying to create buildings, I wouldn't give a penny for their efforts. [14]

Henrik Gedenryd in his 1998 PhD cognitive science thesis *How Designers Work* [15] took a close look at design methods and identified the origins of the analysis-synthesis-evaluation triad back to the Greek mathematician Pappus of Alexandria who in approximately 300 A.D. first explained this triad as the means to go about formulating mathematical geometric proofs.

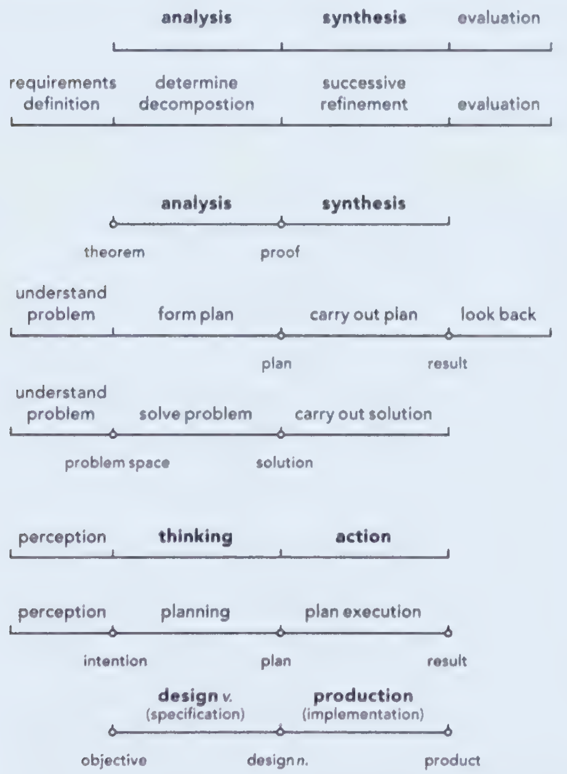

Fig. 7 Gedenryd's "Rosetta Stone" diagram. (from Gedenryd, "How designers work", 56)

Pappus' method no doubt originates much further back probably as far back as Aristotle or Plato, however it is Pappus' explanation of geometric proofs that makes up the foundation of not only design methods but also a wide range of theory and philosophy which, over the

[14] Christopher Alexander, "A Refutation of Design Methodology" (Interview with Max Jacobson) *Architectural Design*, December, 1971.
[15] Gedenryd, "How designers work"

course of history, has tried to explain patterns of thinking and reasoning. These include cognitive science, logic, problem solving, psychology as well as computer science. Gedenryd concludes by devising what he refers to as the "Rosetta Stone of rational action models"[fig xx]. This diagram maps out models from these various fields and points out their underlying structure; they are all variations of the analysis-synthesis-evaluation triad.

Drawings and Thoughts

One common characteristic of all these models besides their adoption of Pappus' model of geometric proofs is a framework of explaining the human thought process as fundamentally abstract, that is to say as removed from the material world. In this framework consciousness is regarded as immaterial, or as Gedenryd puts it[16], intramental. Thought processes, reasoning, etc. are all explained as taking place inside the mind with the material world at best providing inputs and also acting as the place were output is directed.

We can see this at work in Pólya's book *How to Solve It*[17] a guide to solving mathematical problems. In it Pólya gives the "nonmathematical illustration" of Pappus in the form of the problem of a primitive man crossing a stream. When confronted with the impassable stream, the man stops and works out a sequence of steps backwards from his problem/unknown, that is, how to cross the stream.

> The man may recall that he has crossed some other creek by walking along a fallen tree. He looks around for a suitable fallen tree... He cannot find any suitable tree but there are plenty of trees standing along the creek: he wishes that one of them would fall. Could he make a tree fall across the creek?[18]

The man formulates in his mind a sequence of actions: cutting down the tree, the tree falling over the stream, walking on top of the tree and across the stream, etc. "This train of ideas ought to be called analysis"[19]. Once the man has the steps and their order figured out in his mind, he goes on to carry them out in practice. This "translation of

[16] Gedenryd, "How designers work" 67.
[17] George Pólya, *How to Solve It: A New Aspect of Mathematical Method.* (Princeton: Princeton University Press, 1975)
[18] Pólya, *How to Solve It,* 145.
[19] Pólya, *How to Solve It,* 145.

ideas into action"[20] is referred to as the synthesis. The analysis works backwards from the unknown while synthesis work forwards towards it until it is found. At the end of the synthesis stage, the man walks across the stream on top of the fallen tree.

> The same objects fill the analysis and the synthesis; they exercise the mind of the man in the analysis and his muscles in the synthesis; the analysis consists in thoughts, the synthesis in acts [21]

Note the similarities between this process and Jones Chris Jones' summary of the analysis-synthesis-evaluation triad into the steps "breaking the problem into pieces", "putting the pieces together in a new way" and "testing to discover the consequences of putting the new arrangement into practice"[22].

However, recent advances in brain science indicate there may not be anything special about consciousness after all and that the mind and its inner workings can be explained through physical means. For example, one explanation of addictive human behaviour points to the hardwiring of neural pathways in the brain such that whenever a trigger is set off the person is effectively incapable of resisting following through on the hardwired behaviour. This framework would suggest that thoughts and actions are not so easily separated as Pólya describes. Instead they are intricately interconnected.

This new understanding of human cognition is referred to as embodied cognition. Thinking doesn't just happen inside the brain, instead it happens in relation to and because of human anatomy, human actions, and the environment. If we look back to the intramental model and try to map it alongside the analysis-synthesis-evaluation triad it might look something like Figure 7.

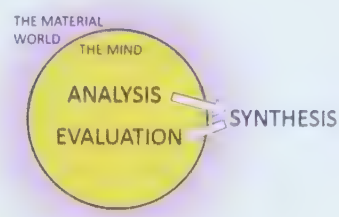

Fig. 8. The analysis-synthesis-evaluation model in relation to the intramental model of the mind. Figure by the author.

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[20] Pólya, *How to Solve It*, 145.

[21] Pólya, *How to Solve It*, 145.

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However, if we assume embodied cognition to be correct, then the separation between analysis synthesis and evaluation goes counter to the new framework. This observation helps us to understand why design methods, and by extension using the computer as a tool in the course of design activity, simply don't work.

When designing on the computer one is forced to breakdown the process precisely in this manner. First it is necessary to go backwards from one's intended outcome and figure out based on experience with the software precisely what actions to take in order to achieve the desired result. Regardless of program, the sequence of steps considered at this point is almost always long and overly complex. Once the steps are determined they are carried out and if all goes well the end result is the finished design. Note how irrelevant the last step of evaluation is in this framework. It cannot be used effectively as feedback unless one decides to go through the whole process all over again taking into account the things learned in the evaluation phase.

So, if this is not a design process, then what does an actual design process look like and what does drawing have to do with it anyway? In order to answer this we can look back to the Renaissance, to Taccola and his drawings of military ships and grapplers. We recall McGee's observations of the drawings and of what they reveal about the activity Taccola is undertaking:

> Taccola's style provides him with a method of systematic investigation through variation...[23]
>
> Taccola's drawing technique allows him to... investigate the future context of use[24]
>
> ...the cause of variation [in the position of the grapplers from one drawing to the next] appears to be Taccola's awareness of awkwardness or ineffectiveness for the humans who actually have to use them.[25]

So, where do these drawings, or better said the activity of drawing undertaken by Taccola fit into the analysis-synthesis-evaluation scheme? Do the drawings constitute analysis - working backwards from an unknown? Do they constitute synthesis – the

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[23] McGee, "The Origins of Early Modern Machine Design," 76.
[24] McGee, "The Origins of Early Modern Machine Design," 78.
[25] McGee, "The Origins of Early Modern Machine Design," 78.

carrying out of a plan forwards based on prescribed steps and towards the resolution of the unknown? Is it a form of evaluation? In a way, the answer to all these questions is yes, but also no. Taccola is trying to figure out what the optimal location of the grapplers is. The position of the grappler is the unknown. But he does not do this by going backwards and trying to figure out some sequence of steps that will lead to this unknown. Instead, Taccola moves forward (as one would in a synthesis phase) with tentative solutions that are in turn tested (evaluated) within the drawings themselves. Therefore, while traces of the analysis-synthesis-evaluation schema can be seen, they are not divided into separate stages. Instead, they are all inseparable from one another and hence simply descriptors of the same activity. Figure 9 illustrates how the analysis-synthesis-evaluation might work within this new framework.

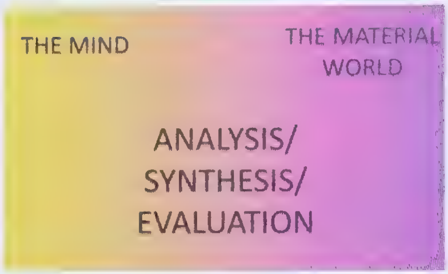

Fig. 9. The analysis-synthesis-evaluation model in relation to embodied cognition. Figure by the author.

Pragmatic Design

Donald Schön provides us with an example of this new understanding of design activity through his contextualization of drawing within the sphere of tacit knowledge and reflective practice. Schön placed an ethnographic study of an architectural design review at M.I.T. from the late 1970s at the center of a number of influential writings regarding reflective practice and education. In this study a student named Petra presents her project for a design of a school to a professor named Quist. The student explains her difficulties in trying to fit her design into a sloping terrain. Quist goes on to change the coordinates of the problem and to approach it with a fresh perspective. He does this type of "move", as Schön calls it, several times:

> Each move is a local experiment that contributes to the global experiment of reframing the problem. Some moves are resisted (the shapes cannot be made to fit the contours), while others generate new phenomena. As Quist reflects on the unexpected consequences and implications of his moves, he listens to the

> situation's back talk, forming new appreciations, which guide his further moves.[26]

Schön's description of the "situation's talk back" is reminiscent of Graves' description of drawings as possessing "a life of their own, an insistence, a meaning, that is fundamental to their existence"[27]. Graves also provides us with an example. He is sitting in a "tedious" faculty meeting at Princeton and out of boredom begins sketching on his notepad. An equally distracted colleague notices his drawing and Graves passes his pad over to him. A "conversation" is started:

> We were engaged in a dialogue over this plan and we understood each other perfectly. I suppose that you could have a debate like that with words, but it would have been entirely different. Our game was not about winners or losers, but about a shared language. We had a genuine love for making this drawing. There was an insistence, by the act of drawing, that the composition would stay open, that the speculation would stay "wet" in the sense of a painting. Our plan was without scale and we could as easily have been drawing a domestic building as a portion of a city. It was the act of drawing that allowed us to speculate.[28]

Designerly intent is imbued within the drawings. Engaging with the drawings means engaging with the design intent of its maker whether that is another person or the person actively working through their own drawings. The conversation between Graves and his colleague is like one among peers. In Schön's example, the conversation takes place between an experienced designer and a student. Hence, Quist performs moves in front of Petra in a deliberate way in order to illustrate *how* to go about designing and overcoming her difficulties. He does not solve the problem for her, but instead shows her by example how to approach the problem, how to retain the "speculative aspect" of the activity, how to keep the exploration "wet", as Graves would put it.

> In exploring a thought through drawing, the aspect that is so intriguing to our minds, I suspect, is what might be regarded as the speculative act. Because the drawing as an artifact is generally thought of as somewhat more tentative than other representational devices, it is perhaps a more fragmentary or open

[26] Donald Schön, *Educating the Reflective Practitioner: Toward a New Design for Teaching and Learning in the Professions* (San Francisco: Jossey-Bass, 1988), 57.
[27] Graves, "Architecture and the Lost Art of Drawing."
[28] Graves, "Architecture and the Lost Art of Drawing."

> notation. It is this very lack of completion or finality that contributes to its speculative nature.[29]

Quist hopes to be able to get Petra to also perceive this speculative quality, he wants her to perceive as he does this malleableity of the drawings and the design context they describe. The marks are not set in stone; instead, they can be changed in order to enable progress. The moves Quist makes are not driven by logic ("You should begin with a discipline, even if it is arbitrary" [30]), but instead they are made *in order to* generate logic and structure. "Coherence must be given to the site in the form of a geometry - a 'discipline' - that can be imposed on it"[31]. Once a move is made, Quist follows it to its logical conclusion. As he does so, he engages in a series of tentative implications of the initial move. In terms of the earlier discussion on design methods this constitutes at once analysis, synthesis and evaluation.

> It is the act of working on a solution that also serves as an implicit test of the problem being solved. Hence, also the outcome of the test is implicit. In particular, success consists in the absence of failure, showing that the problem enables him to make progress, if he like Petra fails to produce a satisfactory solution, then he should probably change the framing again.[32]

It is interesting to note that fairly similar moves are common in other disciplines as well. For example, when an engineer is confronted with a mathematical problem, it is not uncommon to perform a series of calculations not in an attempt to solve the problem, but as a point of inquiry into the nature of the problem itself, to test out the sequence of calculations to see if they lead to an appropriate answer. Sometimes, the initial guess leads to a satisfactory result; however, if the problem is complicated relative to the level of competency or experience of the engineer, then multiple attempts are required. These attempts are not unlike Quist's moves. The difference between a student and a professional engineer comes from the experience of having performed many different types of calculations in the past and when confronted with a new problem to be able to draw from experience and apply it to the new situation. Gedenryd similarly identifies

[29] Michael Graves, *Images of a Grand Tour* (New York: Princeton Architectural Press, 2005), 236.
[30] Schön, *Educating the Reflective Practitioner,* 49.
[31] Schön, *Educating the Reflective Practitioner,* 49.
[32] Gedenryd, "How designers work", 83-84

the ability to perform such moves and maintain the speculative or "wet" qualities as design competency.

> The ability to reframe a problem, to see multiple approaches and to exploit them is what makes the difference between Quist and Petra. "Quist literally makes his problem solvable, whereas Petra finds herself stuck." [33]

These same qualities are evident in Taccola as well. Taccola holds "some elements steady while others are explored in successive iterations of the design"[34]. This is not unlike Quist imposing a "discipline" onto the site. Constraints are created in order to both direct and limit the range of options available as the inquiry progresses. This kind of management of constraints Gedenryd describes as pragmatic. Quist has the ability to adapt while Petra has the tendency to accept her situation as is and to get stuck in a context of her own making. The connection between such design moves and designer imposed constraints which can also be found in Lawson:

> It is obvious that these designer-generated constraints are comparatively flexible. If they cause too many difficulties, or just simply do not work out the designer is free to modify or scrap them altogether. Design students often fail to recognize this simple fact but instead continue to pit their wits endlessly and fruitlessly against insuperable problems which are largely of their own making. One of the most important skills a designer must acquire is the ability critically to evaluate his own self-imposed constraints.[35]

It is important to recognize from these examples, Schön's example as well as Taccola's, that the action performed, that is the sketching, play the role of an investigation or an inquiry. Taccola explores a variety of pulley arrangements and in the process of doing so he learns more about what the actual problem is from the perspective of the end users and he changes the design as he draws accordingly. The final drawing that appears in "De Machinis" contains elements from the various sketches performed previously. The early explorations indicate Taccola had gained new knowledge about the problem and this knowledge and experience is reflected in the final drawing. We can observe the same process at work in Quist's moves.

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[33] Gedenryd, "How designers work", 89.
[34] McGee, "The Origins of Early Modern Machine Design," 76.
[35] Bryan Lawson, *How Designers Think* (New York: Architectural Press, 2006), 91.

Going back to Graves' *New York Times* pieces we can see what he means by drawings as an expression of "the interaction of our minds, eyes and hands." For design, and those disciplines that are predominantly concerned with visual expression, drawing represents the means whereby visual ideas are manifested and acted upon. As they are acted upon, the professional reflects or engages in what Schön calls a "conversation with materials". central mode of operation, that is to say, the core mode of thinking. While in engineering or science, or accounting, the mode of thinking may be purely logical mathematical, or in humanities it might be a form of expression through language, in design and those disciplines related to it like visual art, architecture, etc., the primary mode of thinking is visual and drawings are the most immediate means to express thoughts.

Without the ability to sketch or to perform some action that carries the same function one is simply implementing a plan or following through a series of steps whether prescribed by a design method or the logic of a software package. Instead, one should seek to be engaged in actively designing or at least performing an inquiry into the context of design.

PART 3: ALTERNATIVES

In the 2006 documentary *Sketches of Frank Gehry* we can observe what one might refer to as a modern master, that is, the architect Frank Gehry, working and designing in a contemporary context. Despite the title of the film, Gehry's design process is actually not comprised of much sketching activity. The sketches referred to in the title of the film are few, are made very early on and are very loose, allowing for a great deal of interpretation. They describe a vague idea that acts as a starting point for exploration and iteration which predominantly takes the form of three-dimensional models at varying scales. It is in this stage of modelling in three-dimensions that Gehry actually works on his designs. Later, the final model is scanned and turned into a 3d model to be cleaned up and sent to engineers, manufacturers, and clients.

Gehry's working methods are interesting due to the various tensions present within it. For instance, there is the tension between the initial drawings and the later stage of 3d modelling. Gehry admits that for many years he subscribed to the orthodoxy within his profession, effectively trying to design relatively quiet, conventional buildings primarily through plan and sections. However, his drawings revealed a different sensibility to that of his commercial work.

> I loved the shaping I could do when I'm sketching and when I was doing it, it never occurred to me that I would do it in a building.[36]

Part of the reason why Gehry's buildings are so striking is due to his working process which makes designing activity possible relatively late in the development of a design. The early sketches represent the most direct form of expression of his intent. However, it's important to note, that for him, it does not stop there - this kind of freedom is extended into the 3d modelling phase. The models made by his design partners are not just a means of visualizing a potential final product. Instead, they are actively used and acted upon during the process of designing.

> GEHRY: [looking at a rough model] ...well, let's look at it for a while and be irritated by it, then we'll figure out what to do.
> POLLACK: What don't you like?

[36] Frank Gehry, *Sketches of Frank Gehry*, directed by Sydney Pollack (2006; Los Angeles, CA: Sony Pictures Classic, 2006), DVD.

> GEHRY: I don't know yet. It seems a little pompous, a little pretentious... this is the part that I don't know how to put in words.[37]

Gehry's models are effectively a form of 3d sketching similar to design activities described by Schön, Gedenryd, McGee, and Graves. This notion of 3d sketching is crucial for those disciplines that concern themselves with three-dimensional forms. How can one capture the intricacies of a Gehry design, or any 3d design for that matter, by making flat drawings? Rowena Reed, an early influential American educator in industrial design was adamant about this point.

> All three-dimensional projects should be designed three-dimensionally. You can't develop a good three-dimensional design on paper.[38]

A second tension evident in Gehry's work is that between traditional tools like model making and the use of computers. On the one hand, design activity is entirely driven by traditional tools. It is in these stages that we can observe actual designing taking place. Only after this is finished do the models ever go on to become digital. Gehry admits openly he personally does not use a computer almost at all. However, the use of digital tools that are very accurate and which permit the scanning of real life objects is also what makes possible the geometric complexity of Gehry's buildings.

These tensions are notable in Gehry's work primarily due to the relatively neat ways in which they are dealt with. Instead of being obstacles, the various jumps from 2d to 3d, from traditional to digital, etc. are used by Gehry in a pragmatic way much like how Quist takes advantage of the various constraints in Schön's examples. Each method or tool Gehry employs is exploited based on its strengths and weaknesses, but, more importantly, based on how they complement his design intent and his desire to make a design "move", to try out a particular idea and have it manifested visually such that it can be acted upon.

In the practical project I present here I make an attempt to arrive at a process, like Gehry's, in which tools are adopted in an opportunistic way in order to enable the kind of exploration desired as opposed to allowing tools to dictate the realm of design

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[37] Frank Gehry, *Sketches of Frank Gehry*.

[38] Rowena Reed, quoted in Gail Greet Hannah, *Elements of Design: Rowena Reed Kostellow and the structure of visual relationships.* (New York: Princeton Architectural Press, 2002), 40.

possibilities. I also attempt to arrive at a context appropriate solution to the problem of how to follow a design drawing phase with a similar activity in three-dimensions. The project consists of conceptual designs of fencing sport equipment, primarily masks and suits. Its purpose is not to address a real world problem, but instead to address the processual concerns listed above and to explore the relationship between 3d modelling, authentic design activity and drawing. The project also addresses tensions similar to those present in Gehry's work; between 2d and 3d, between the freedom of traditional tools and the limits but also enabling qualities of new technologies. However, in my own process, a crucial distinction is made. I attempted to incorporate digital tools into the activity of designing itself as opposed to leaving it, as Gehry does, for the end as a drafting tool. This approach to using computer tools as a part of design activity is made possible by recent advances in gestural interfaces and software. In particular, I am referring to 3d "sculpting" tools which in fact don't really allow for sculpting but a kind of drawing on a 2d surface (a Wacom or a Cintiq tablet) whose end product is a 3d digital model.

Fig. 10. Illustration of modelling in Zbrush.

The process of virtual sculpting is best illustrated in relation to more conventional 2d drawing and painting software like Corel Painter or Photoshop. In these packages, the pressure sensitivity of a Wacom stylus is assigned as a modifier of various stroke properties. By altering which properties are controlled and how, the stylus becomes a drawing instrument, a paintbrush, or it can be used to achieve more unusual effects.

Digital sculpting extends this concept into three-dimensions by having the pressure sensitivity control a z-axis perpendicular to the surface of a 3d model (i.e. along the normal of a face). For example, the stylus pressure can be used to control the amount of displacement along the z axis away from the surface. This means that volume can be added to a 3d model according to the gestural moves of the user.

The use of gestures brings into focus what Schön describes as the designer's "sensorial appreciation". For Schön sensorial appreciation is important in enabling a designer to engage with the materials before him.

> The design situation is a material one, apprehended, in part, through active, sensory appreciation... Through active sensory appreciation the designer constructs and reconstructs the objects and relations with which he deals, determining "what is there" for the purposes of design[39]

Schön makes the link to competency and engagement with the substance or meaning behind the materials the designer engages with.

> I'm writing on this pad now with a pen. As I guide the pen along the paper, I am not paying attention to the pressure of my fingertips on the pen... I'm paying attention to the content of what I am writing, rather than to the process of writing. I manipulate the mark on the paper from a sensory base of which I am systematically unaware. In fact, I have to become unaware of it to become expert in using the pen. The sensory basis on which I use the pen becomes invisible if I know how to use the pen well.[40]

In a digital sculpting process the sequence of steps that take a model from being a simple base mesh and into a complex model are entirely determined by the user and the end result is wholly dependent on his/her ability to convey the shapes and forms that are in his/her imagination. Competency with software like ZBrush lies not in understanding the logic of the software and knowing where the buttons are and what order to press them in order to arrive at a desired outcome. Instead, competency lies in the ability to give structure to a set of almost infinite possibilities. It is by necessity a creative act of invention and it is driven by self-imposed constraints.

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[39] Donald Schön, "Designing as a Reflective Conversation with the Materials of a Design Situation", keynote, Edinburgh Conference on Artificial Intelligence in Design, June 25, 1991.
[40] Schön, Donald. "Reflective Conversation with Materials." Interview by John Bennett. Stanford University. Web. 23 Aug. 2014. <http://hci.stanford.edu/publications/bds/9-schon.html>

Contrast this with the paradigm of currently widely used digital tools. Take for example Rhino, which is an evolution of AutoCAD, which in turn is one of the most ubiquitous 2D drafting software. 3D forms in Rhino are best generated out of 2D shapes. First the 2D shapes are drawn as desired and then the 3d forms are extruded, revolved or swept across other 2D lines in various ways. This process describes a traditional CAD environment.

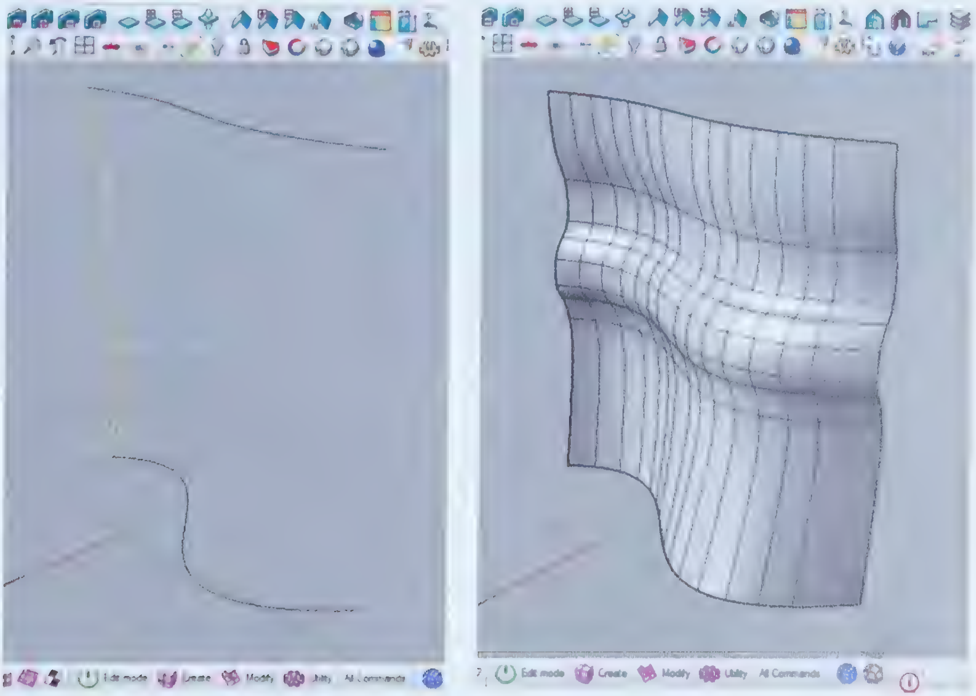

Fig. 11. Illustration of modelling in Rhino.

Traditional CAD has evolved into the paradigm of parametric modelling of which good examples can be seen in Revit or Solidworks. However, for the purposes of illustrating the concept, we can take a look at 3DS Max's modifier stack, which while not being exactly a full implementation of the parametric paradigm is a good examples of the basic principle and will serve our purposes. In 3DS Max 3D forms are first generated out of primitives, that is, platonic geometric shapes like cubes, pyramids, cones, etc. The modifier stack is, as the name implies, a linear stack of modifications that can be applied to an object. So, for instance, one can choose to bend the shape a certain amount, or twist it by a particular angle. This sequence of modifications is accumulated in the stack. Figure 3.2 illustrates this profess. The first 4 screenshots show a cube having a variety of

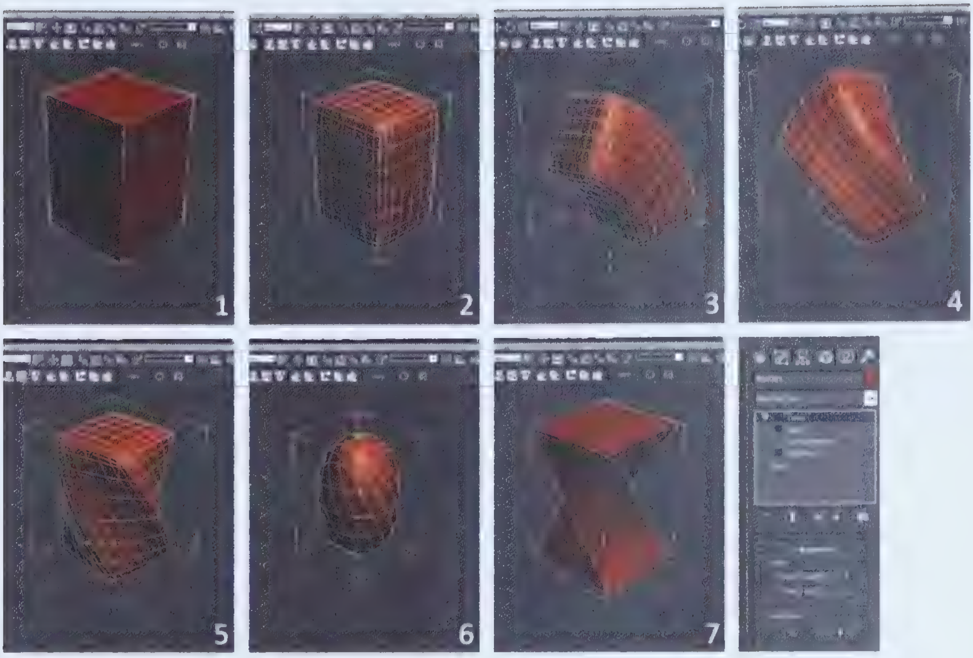

Fig. 12. Illustration of parametric modelling inside 3Ds Max.

modifiers added to its modifiers stack (you can see the stack in the bottom right corner). In screenshots 5 through 7 some of the modifiers are turned off while others are left on; the resulting shape is always a combination of the active modifiers. Furthermore, each modifier contains variables which can be changed on the fly like, for example, the angle of rotation of the twist modifier. Crucially, in the parametric paradigm, this sequence of steps is represented by variables which can be changed in relation to one another. This effectively gives the designer more freedom to go back and change things later.

The problem with this paradigm is simply that the designer has to continually break down his/her intended action into these steps as prescribed by what the software itself can do. In relation to the previous discussion of design methods this is akin to following through with the prescriptions of a strict design method instead of reacting in a pragmatic way (as Quist does in Schön's example) to the "talk back"[41] of the design context. What is possible in the software in terms of geometry has a profound effect on the kinds of shapes and designs that come out as a result. This is especially evident in a lot of modern design that embraces these digital tools. The intent of the designer can

[41] Schön, *Educating the Reflective Practitioner*, 57.

easily get lost while the prescriptive logic of the software dictates at every turn how the design will progress and how it will end up at the end.

Rhino, Revit, 3DS Max and other similar software possess the same kind of product-process symmetry Gedenryd argues is evident in Pappus' original analysis-synthesis-evaluation triad:

> The basic mistake that Pappus made was to conflate the structures of the resulting proof, and that of the process that produced it. Most likely, this was because the method was established not from observing the actual work behind the proof, but only the result of this work—that is, the proof itself. [42]

This means that the structure of the design process is confused with the structure of the final design in the same way that Pappus confused the problem solving process with the structure of the resulting geometric proof. It makes sense for the software designer to try to break down the process of arriving at a particular end product into its logical constituent steps. It does not necessarily make sense for a designer to follow such a process. Schön points out that structure is imposed on a context and tested to see if it works. The absence of failure constitutes success, not necessarily building logically on a previous step.

Unlike these commonly used software, Zbrush makes possible a sketch-like evolution of 3d models. This activity can act as a form of inquiry into a design situation, or as Schön might put it, a "reflective conversation with materials" [43]. This relationship between drawings and digital sculpts are the object of exploration of the final thesis project. Importantly, I wanted to undertake this exploration by going freely between drawing and 3d modelling effectively using digital sculpting as part of the activity of designing. This would serve as a test to see if the assumptions that I had about digital sculpting were true. Can a 3D digital paradigm like this be used for actual designing? Does digital sculpting really possess the same kind of qualities as drawing to enable, as Schön puts it, "talk back"?

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[42] Gedenryd, "How designers work", 62.
[43] Schön, "Reflective Conversation with Materials."

CONCLUSION

My own experience has been that digital sculpting or any 3D modelling cannot act as a replacement for drawing. Oftentimes precisely because drawings are two-dimensional, the designer can get away with only drawing those things which are immediately relevant for designing at that particular moment in time. In making a 3D model one must by necessity model the entirety of the 3d form. Due to this added complexity it is harder to focus or control the evolution of a design when modelling in 3D. However, in comparison to existing and dominant paradigms of CAD Zbrush represents a radical break. These traditional software are excellent drafting tools however they are not tools that can be used actively in designing. Zbrush, while not being able to provide as much freedom and direction as a sketching or drawing activity, does indeed possess the qualities that characterize drawing and make is so central to design activity. One can indeed engage with digital sculpting tools as one would engage with drawing on the level of a "conversation with materials". In the practical project I try to emphasize this connection between drawing and the new 3D sculpting paradigm.

I argue that designers should seek to adopt digital (or other) tools more in this manner and less based on industry expectations or using technology for its own sake. Especially in light of new and evolving paradigms in the design of software, the possibilities for designing in 3d like Gehry, while at the same time having the kind of freedom one can expect from drawing or sketching, is increasingly becoming a reality.

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Appendix A

Exhibition and works

This section is comprised of documentation of the practical projects I undertook for completion of my master's degree. The work was exhibited in the Fine Arts Building Gallery from August 26 to September 20, 2014 as part of the group show "7; Explorations in design research, practice and education". The various pieces are presented in the show and in this paper in such a way as to emphasise the figural, gestural qualities of the sport of fencing. Initially the project began simply through drawing for its own sake (Figures 15, 16, & 22). At this stage there was no sense of what the purpose of these drawings might be other than to satisfy my own need to record these visual ideas that were beginning to form about fencing equipment. It was only later that I realized there was potential there for a more elaborate project. Much of the work that followed served to contextualize the work, to make sense of it, or as Quist might put it, to "impose a discipline". I progressed not knowing necessarily where I would end up. It was not until a good many months later that I realized drawing lies at the heart of all the work I was doing, even the digital 3d modelling. Ultimately the absence of any major setback led to progress and eventually a well-developed project with complementing practical project and written component. The show itself represents not so much the story of what happened in a sequence so much as an attempt by myself to arrange the work in a manner that makes sense of the activity.

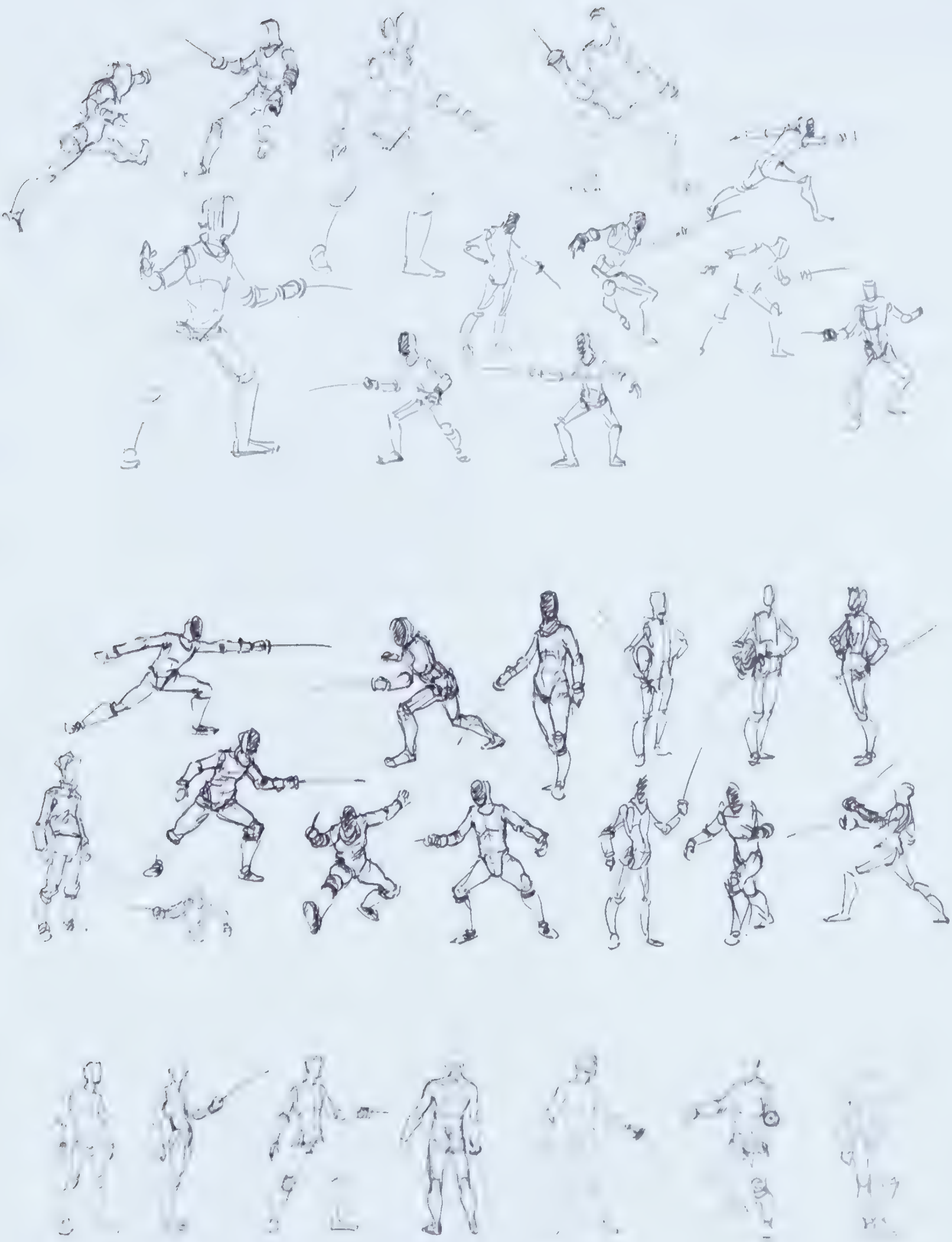

Fig. 13. Gestural studies. Digital sketches.

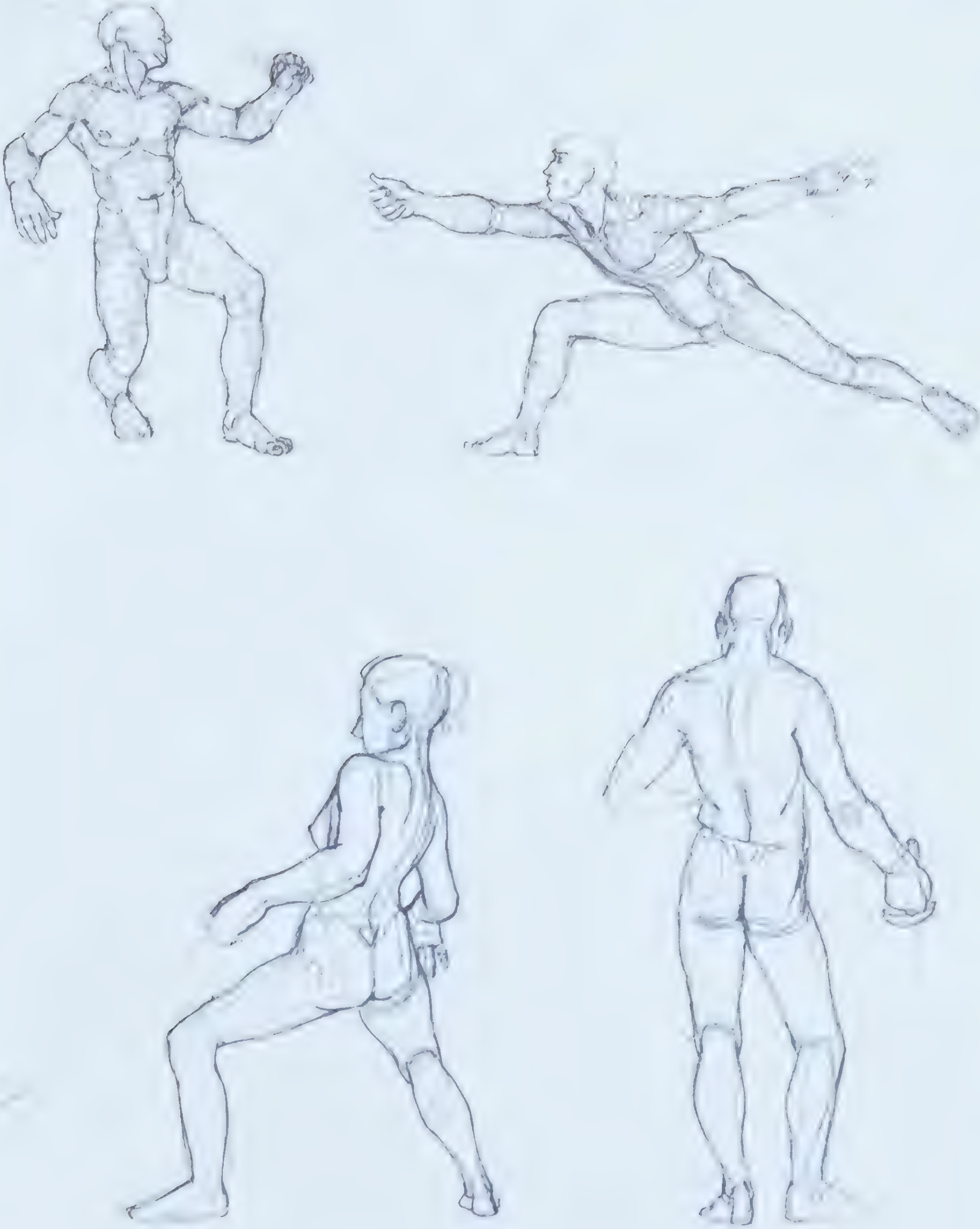

Fig. 14. Fencing figures and poses studies. Traditional drawings.

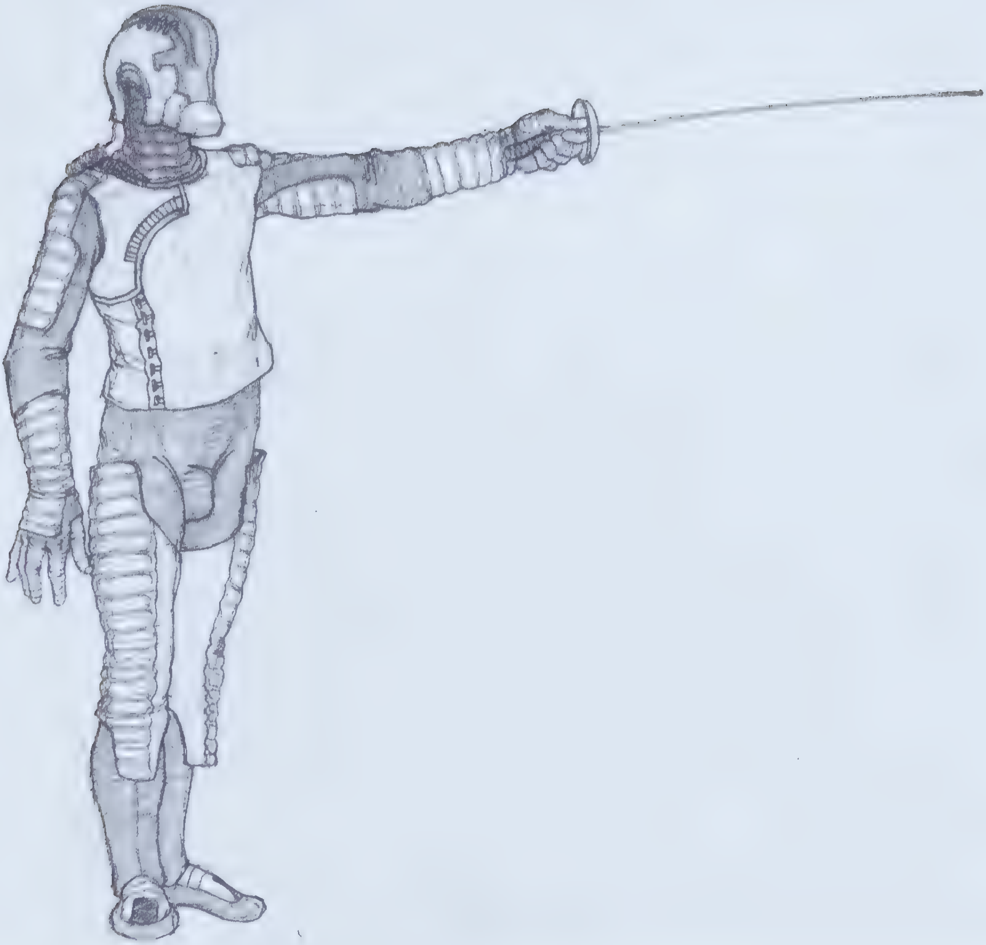

Fig. 15. Fencing suit study I. Traditional drawing.

Fig. 16. Fencing suit study II. Traditional drawing.

Fig. 17. Fencing suit study III. Traditional drawing.

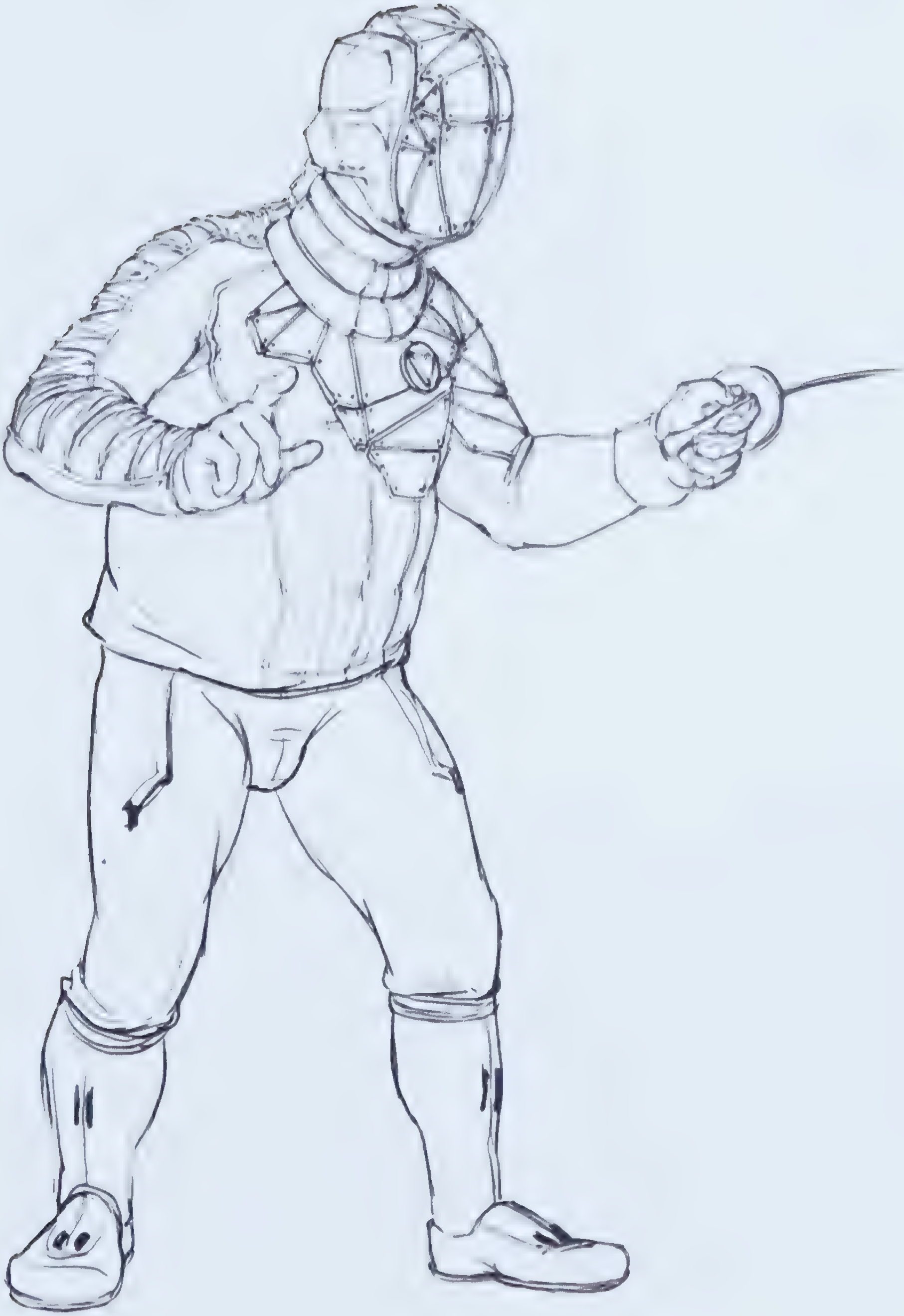

Fig. 18. Fencing suit study IV. Digital drawing.

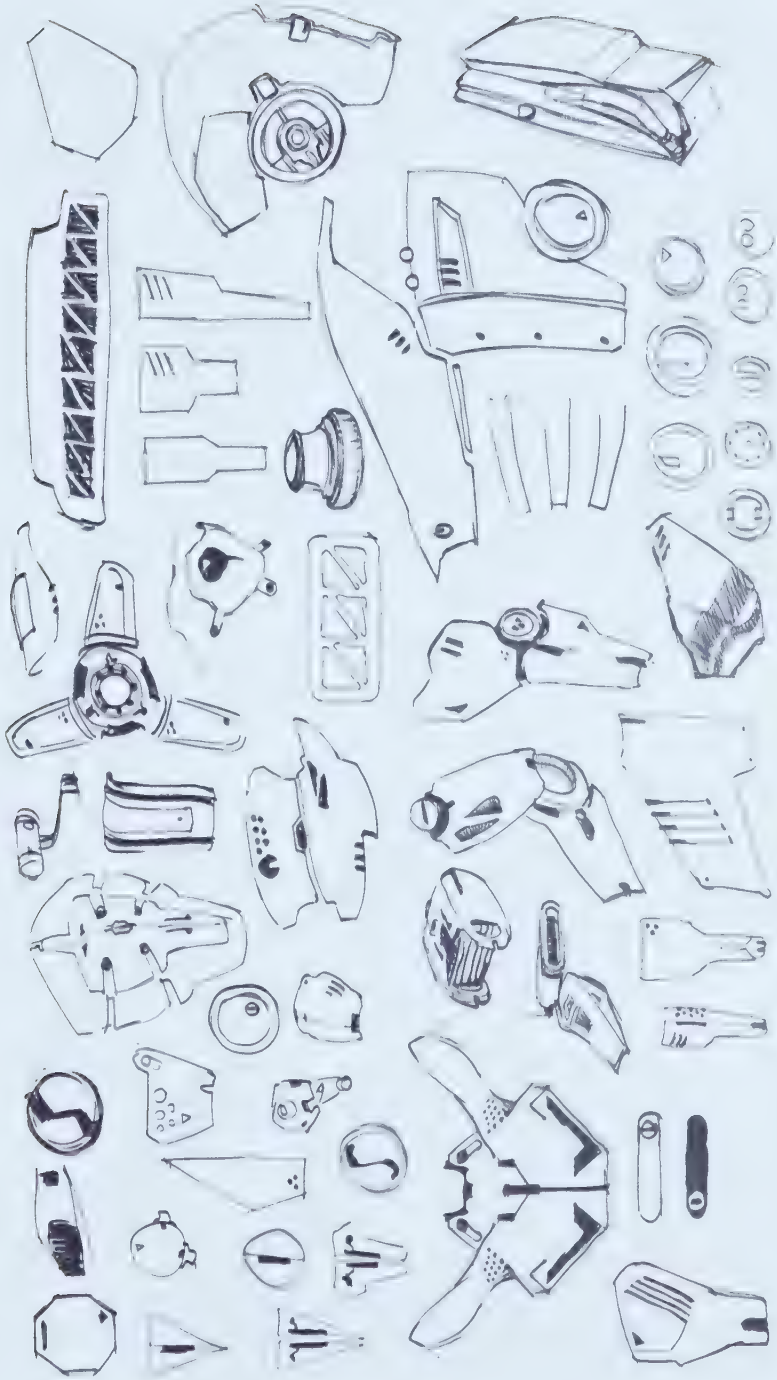

Fig. 19. Hard surface shapes studies. Digital sketches.

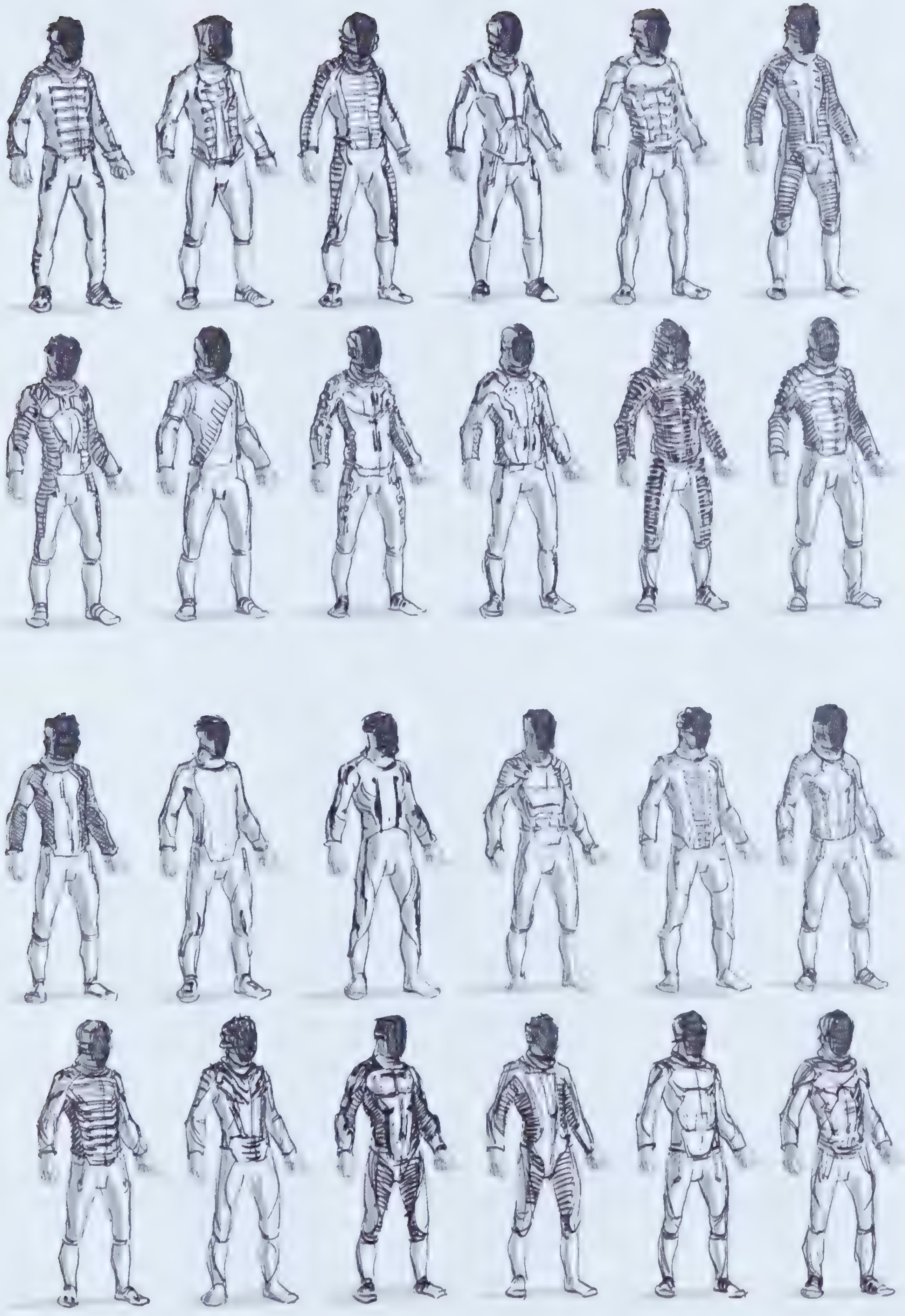

Fig. 20. Fencing suits variety studies. Digital sketches.

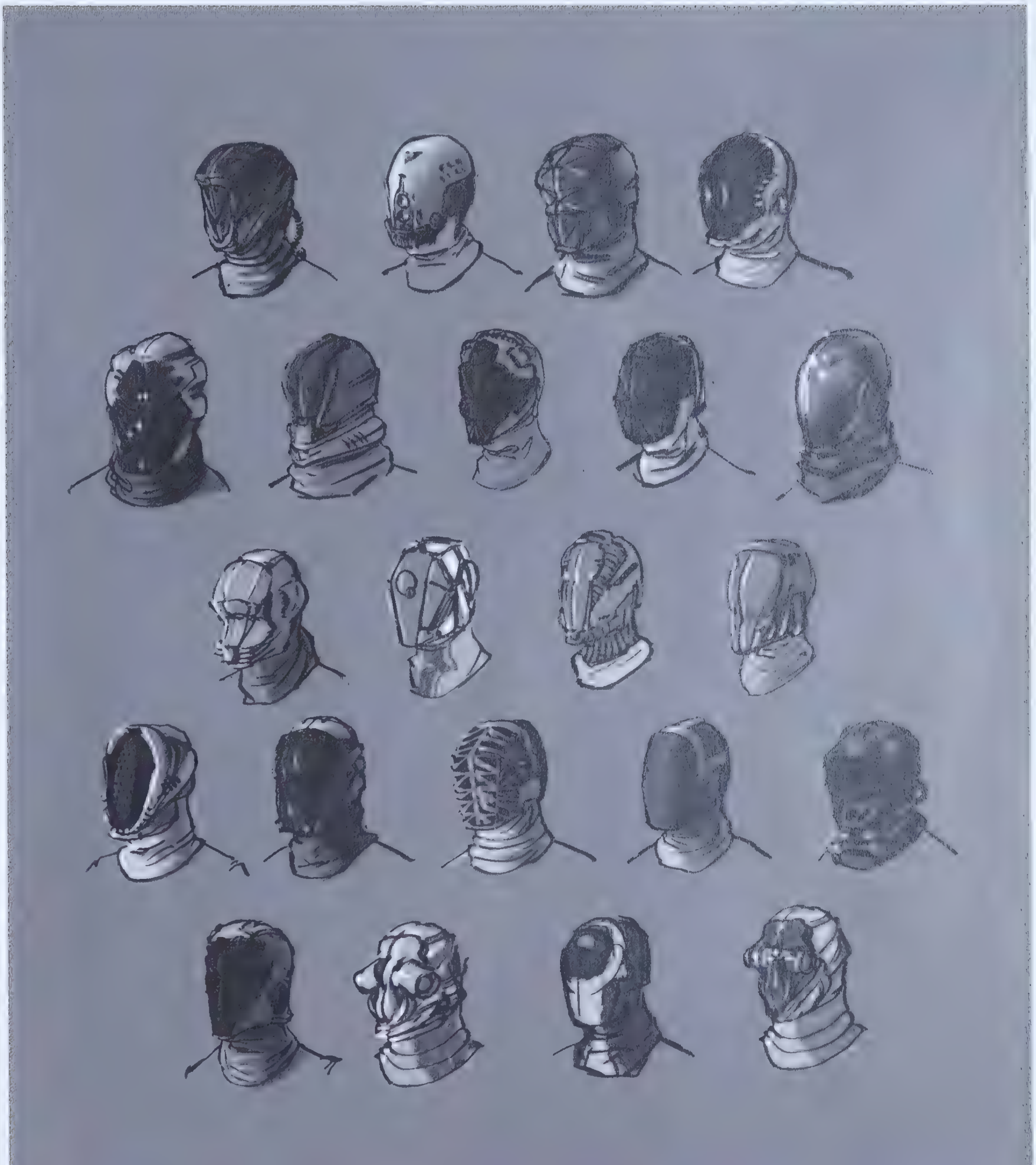

Fig. 21. Fencing masks studies I. Digital sketches.

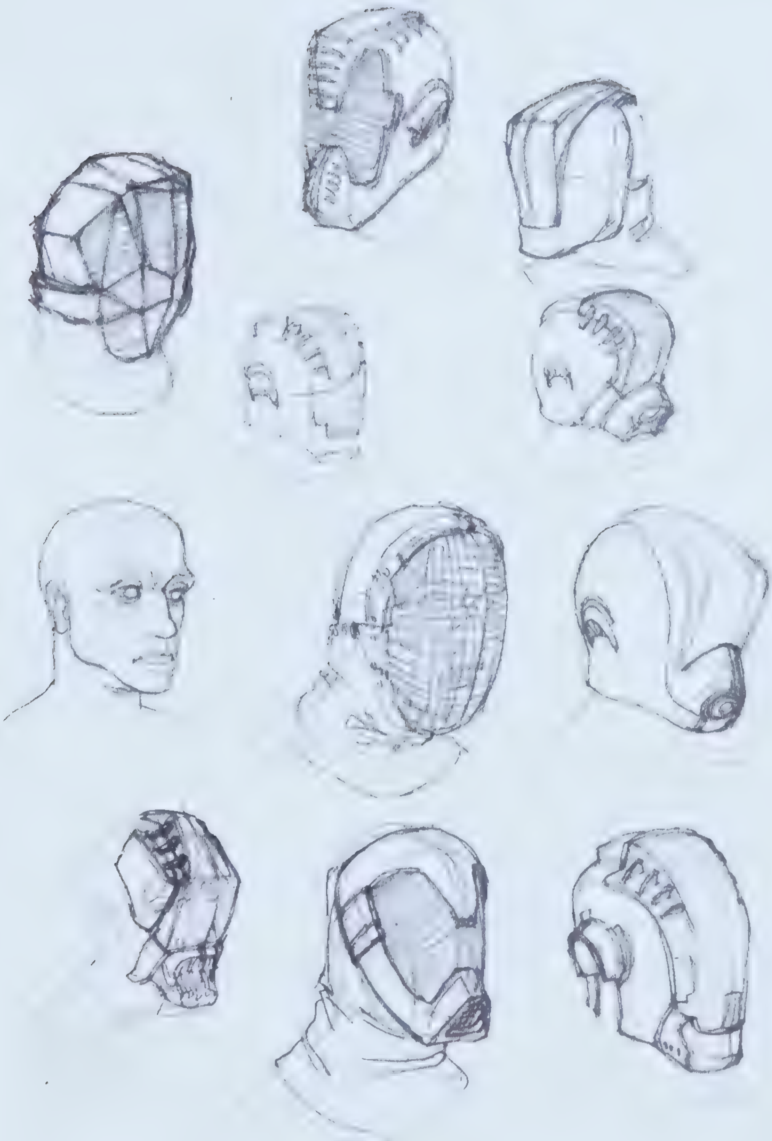

Fig. 22. Fencing masks studies II. Traditional drawings.

Fig. 23. Fencing masks studies III. Digital sculpts.

Fig. 24. Fencing suits studies. Digital sculpts.

Fig. 25. Fencing suits studies (detail of previous). Digital sculpts.

Fig. 26. Fencing suit study rendering I. Digital 2d rendering.

Fig. 27. Fencing suit study rendering II. Digital 2d rendering.

Fig. 28. Fencing suit study rendering III. Digital 2d rendering.

Fig. 29. Fencing suit study rendering IV. Digital 2d rendering.

Fig. 30. Fencing suit study rendering V. Digital 2d rendering.

Fig. 31. Fencing suit developed study female. Digital sculpt.

Fig. 32. Fencing suit developed study male. Digital sculpt.

Fig. 33. Fencing suit developed study female (alternate views). Digital sculpt.

Fig. 34. Fencing suit developed study male (alternate views). Digital sculpt.

Fig. 35. Photo documentation of exhibition I.

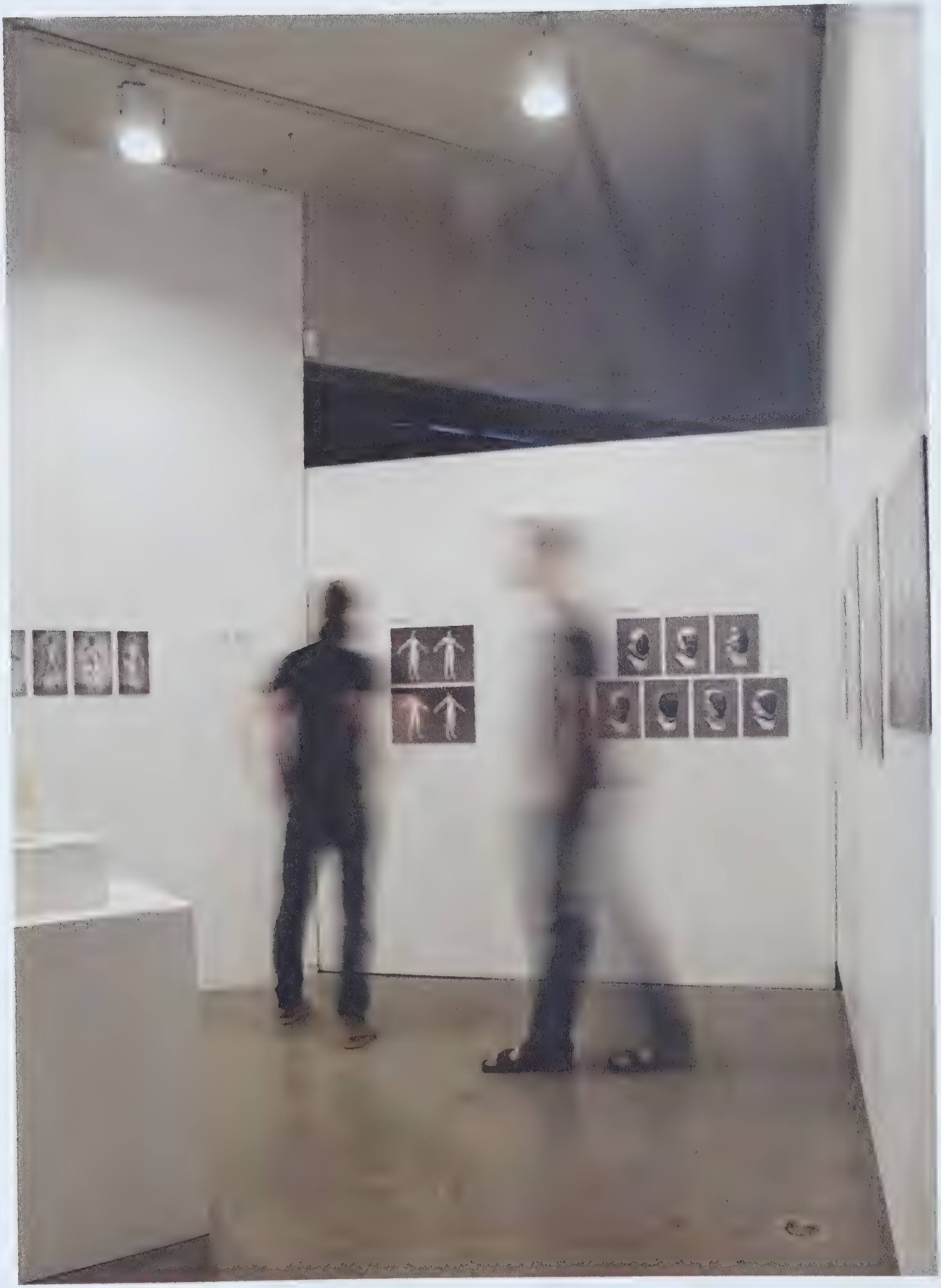

Fig. 36. Photo documentation of exhibition II.

Fig. 37. Photo documentation of exhibition III.

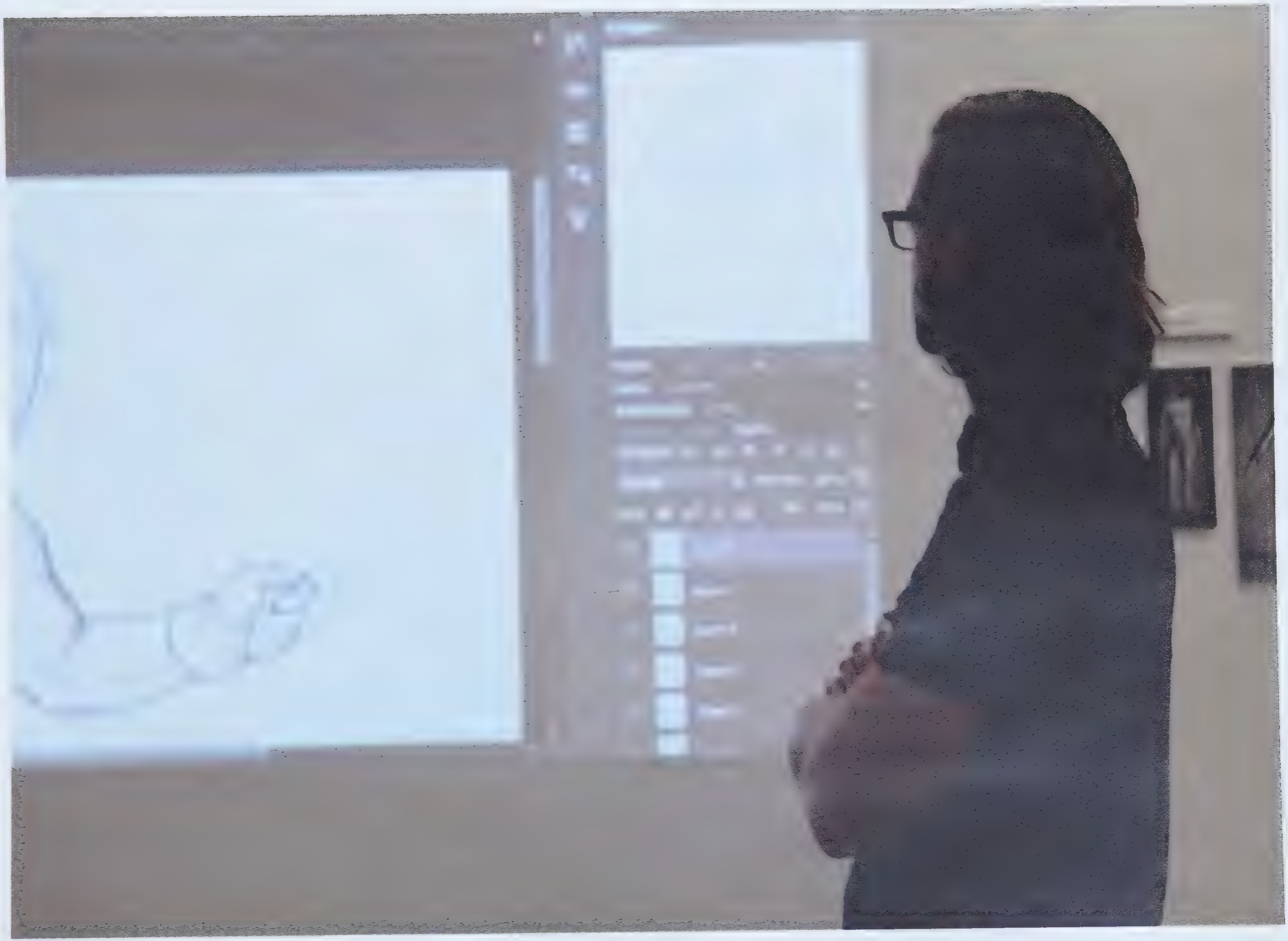

Fig. 38. Photo documentation of exhibition IV.

Fig. 39. Photo documentation of exhibition V.

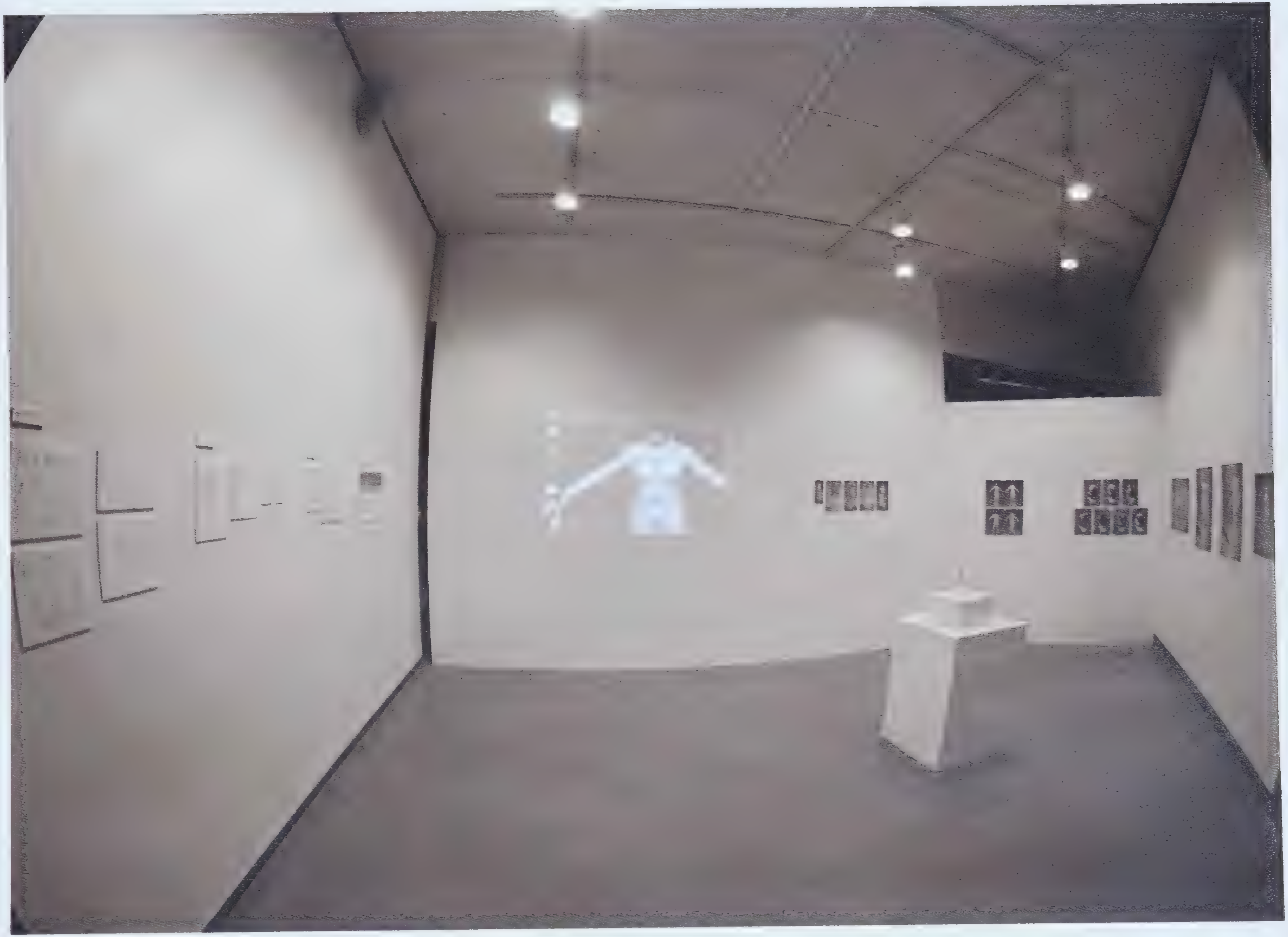

Fig. 40. Photo documentation of exhibition VI.


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